Operating Costs and Energy Demand of Wastewater Treatment Plants in Austria: Benchmarking Results of the Last 10 Years

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Abstract: This work presents operating costs and energy consumption of Austrian municipal WWTPs (≥10,000 PE-design capacity) classified into different size groups. Different processes as well as cost elements are investigated and processes with high relevance regarding to operating costs and energy consumption are identified. Furthermore, the work shows the cost-relevance of six investigated cost elements. The analysis demonstrates the size-dependency of operating costs and energy consumption. For the examination of the energy consumption the investigated WWTPs were further classified into WWTPs with aerobic sludge stabilisation and WWTPs with mesophilic sludge digestion. The work proves that energy consumption depends mainly on the type of sludge stabilisation. The results of the investigation can help to determine reduction potentials in operating costs and energy consumption of WWTPs and form a basis for more detailed analysis which helps to identify cost and energy saving potentials.

Keywords: energy consumption; energy self-sufficiency; operating costs; WWTP benchmarking

Introduction:

Wastewater treatment plant (WWTP) benchmarking contributes to the identification of optimisation and cost reduction potential (Lindtner *et al.* 2008). As stated in Foladori *et al.* (2015), an energy saving potential is almost always present in WWTPs. Baumann & Roth (2008) and Haberkern *et al.* (2008) describe target and guide numbers for the evaluation of energy efficiency of WWTPs. A detailed energy analysis can help to identify optimisation potential and to reduce energy consumption at each stage/process/unit of a WWTP, whereat the increase of energy efficiency does not involve necessarily significant investments (Foladori *et al.* 2015). Performance indicator systems for WWTPs are described in literature (e.g. Balmér & Hellström 2012, Quadros *et al.* 2010). In Austria a benchmarking method was developed from 1999 to 2004; the aim is the identification of best performing WWTPs and the determination of cost reduction potentials to improve the cost efficiency (Kroiss & Lindtner 2005). Within the last 10 years almost every second Austrian municipal WWTP treating more than 10,000 population equivalents (PE, expressed as PE-design capacity) participated at least once in the annual benchmarking. With regard to PE, about 56% of the Austrian municipal WWTP capacity is included in the benchmarking data pool. The representativity of the data for all Austrian WWTPs was investigated and confirmed (Lindtner & Vohryzka 2015). This work investigates operating costs and energy consumption data from 104 Austrian municipal WWTPs (≥10,000 PE) which participated at least once in the annual benchmarking in the years 2003 to 2013, whereof 16 WWTPs are treating more than 100,000 PE. All costs are indexed to the year 2013 and in cases where a WWTP participated more than once, mean values are calculated. This work shows the results of the analysis and interpretation of the benchmarking pool data and provides an insight into operating costs and energy consumption of Austrian municipal WWTPs. All investigated WWTPs fulfil the legal requirements regarding wastewater treatment (95% biochemical oxygen demand-, 85% chemical oxygen demand- and 70% total nitrogen-removal; total phosphorus threshold 0.5 or 1.0 mg/L depending on plant size and receiving water).

Methods:

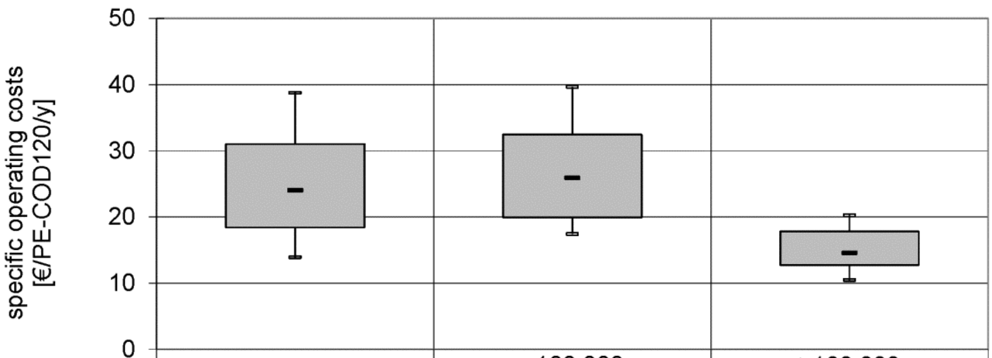
The Austrian Benchmarking Method is described in detail in Lindtner *et al.* (2004). To enable the comparison of WWTPs of different process and operation modes, operating costs of wastewater treatment plants are split into the following main and support processes: mechanical pretreatment (process 1; P1), mechanical-biological wastewater treatment (process 2; P2), sludge thickening and stabilisation (process 3; P3), further sludge treatment and disposal (process 4; P4), obligatory processes (support process I; SPI) and optional processes (support process II; SPII).

For each process yearly specific operating costs and specific energy consumptions are calculated based on annual data provided by the plants, whereat the operating costs are split into six cost elements (i.e. personnel costs, energy costs, residue treatment costs, material costs, external costs and other costs). Specific costs and specific energy consumptions are based on organic pollution load expressed in PE-COD120 (120 g chemical oxygen demand/PE/d corresponding to 60 g biochemical oxygen demand during 5 days/PE/d).

Results and Discussion:

<u>Operating costs:</u>

Figure 1 illustrates the specific total operating costs of the investigated WWTPs and shows that specific operating costs decrease with increasing design capacity (economy of scale). The yearly specific operating costs of the investigated large plants (≥100,000 PE) are 14.6 €/PE-COD120/y (median) and thus considerably smaller than of WWTPs <100,000 PE.



	all WWTPs	<100,000 PE-design capacity	≥100,000 PE-design capacity
number	104	88	16
75th percentile	31.0	32.5	17.8
90th percentile	38.8	39.7	20.3
10th percentile	13.9	17.4	10.5
median	24.1	25.9	14.6
25th percentile	18.4	19.9	12.7

Figure 1: Specific operating costs of municipal WWTPs in Austria

The detailed analysis of the operating costs is shown in figure 2 and figure 3. Figure 2 shows that personnel costs are the most relevant cost element at the investigated WWTPs. Energy costs contribute with 17 respectively 11% to the total operating costs of WWTPs and hence are from lower importance regarding operating costs. Figure 3 shows that support process I (obligatory processes; i.e. laboratory and monitoring, administration, operation building and infrastructure) and process 4 (further sludge treatment and disposal; i.e. dewatering, reuse/disposal) are the most cost-relevant processes on small as well as on large WWTPs. Process 2 (mechanical-biological wastewater treatment; i.e. aeration, biogas utilisation, phosphorus precipitation), the most important process with regard to water pollution control, distributes with only 22 respectively 18% to the total operating costs.

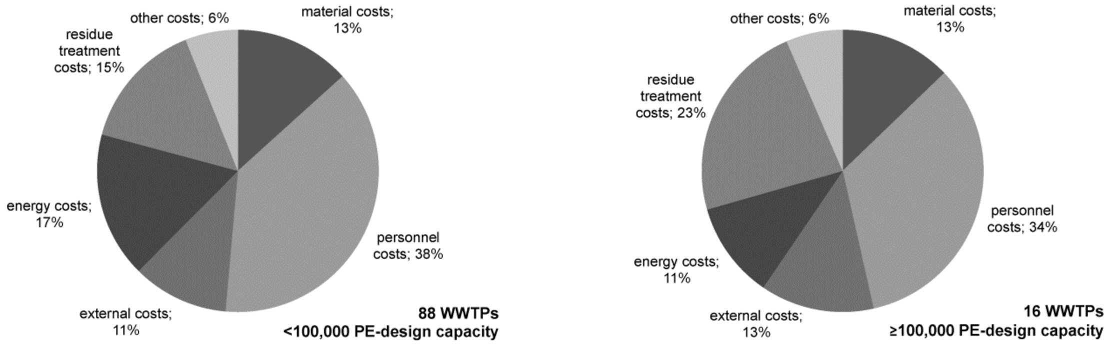


Figure 2: Distribution of cost elements of total operating costs of small and large municipal WWTPs in Austria

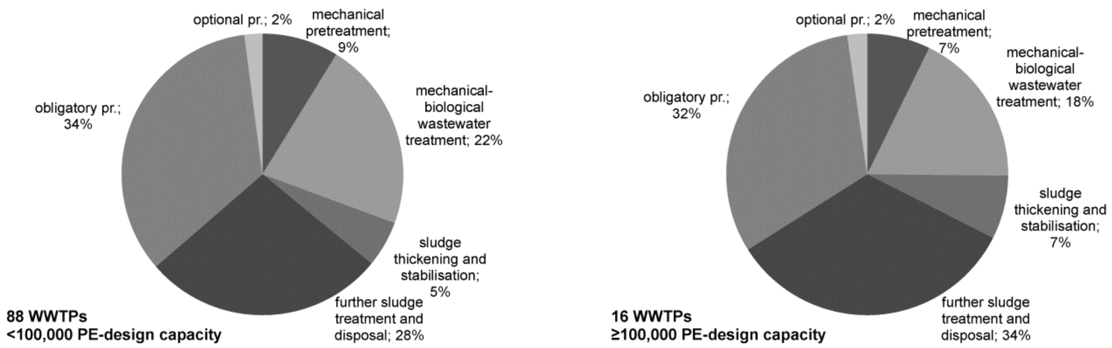
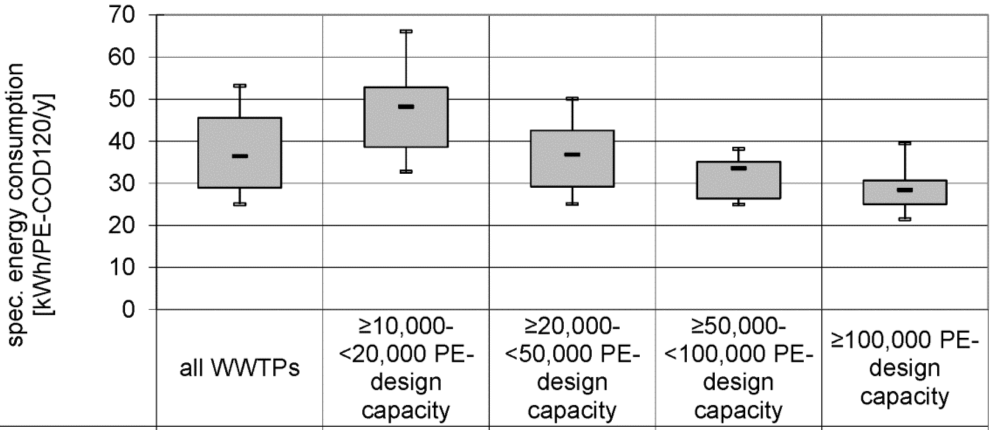


Figure 3: Distribution of processes of total operating costs of small and large municipal WWTPs in Austria

Energy consumption:

For the following investigations the data of 2 WWTPs were excluded because of implausibility (specific total energy consumption ≤15 kWh/PE-COD120/y).

Figure 4 illustrates the specific energy consumption of the investigated WWTPs classified into four groups depending on their plant size. The median of the specific energy consumption of all WWTPs amounts to 36.5 kWh/PE-COD120/y. Although, variability between the different WWTP sizes is high. The figure demonstrates the size dependency of the energy consumption on WWTPs. One reason is the fact, that small WWTPs, especially WWTPs treating less than 20,000 PE, stabilise their sludge aerobically and therefore consume more energy.



	all WWTPs	≥10,000-<20,000 PE-design capacity	≥20,000-<50,000 PE-design capacity	≥50,000-<100,000 PE-design capacity	≥100,000 PE-design capacity
number	102	24	55	7	16
75th percentile	45.6	52.8	42.6	35.1	30.7
90th percentile	53.2	66.1	50.1	38.2	39.5
10th percentile	25.1	32.8	25.1	25.0	21.5
median	36.5	48.2	36.8	33.6	28.4
25th percentile	29.0	38.6	29.3	26.4	25.0

Figure 4: Specific energy consumption of municipal WWTPs in Austria (data without outliers)

Table 1 shows the specific energy consumption of the investigated WWTPs classified into their type of sludge stabilisation. Each category is further subdivided into the plant size. The table shows that WWTPs with aerobic sludge stabilisation have a higher specific energy consumption (about 6 kWh/PE-COD120/y) than WWTPs with mesophilic sludge digestion. This table confirms the dependence of energy consumption on plant size and technology, as also described in literature (Krampe 2013, Mizuta & Shimada 2010).

Table 1: Specific energy consumption of municipal WWTPs in Austria subdivided into WWTPs with aerobic sludge stabilisation and mesophilic sludge digestion respectively (data without outliers)

spec. energy consumption [kWh/PE-COD 120/y]	**all WWTPs**	**WWTPs with aerobic stabilisation**		**WWTPs with mesophilic sludge digestion**	
		≤50.000 PE	**>50.000 PE**	**≤50.000 PE**	**>50.000 PE**
number	102	38	1	41	22
25th percentile	29.0	33.6	34.8	29.2	25.2
median	36.5	42.2	34.8	36.8	28.4
75th percentile	45.6	49.9	34.8	42.5	34.2

Figure 5 illustrates the specific energy consumption of the investigated WWTPs. In this figure the WWTPs are subdivided into their type of sludge stabilisation technology. The median of the specific energy consumption of WWTPs with mesophilic sludge digestion amounts to 33 kWh/PE-COD120/y and is about 10 kWh/PE-COD120/y lower than of WWTPs with aerobic sludge stabilisation.

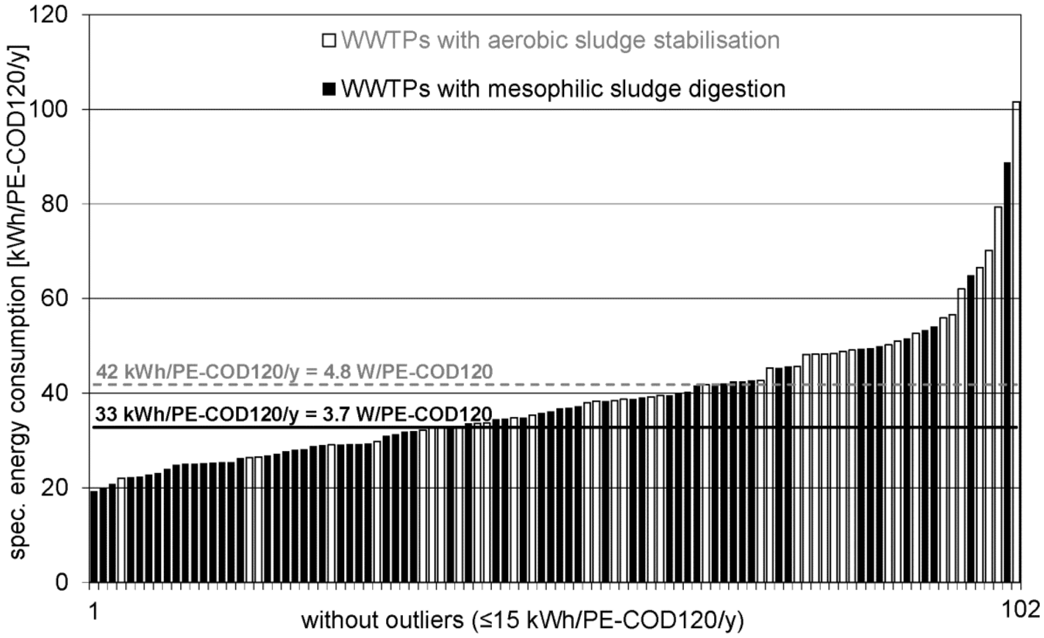


Figure 5: Specific energy consumption and energy demand of municipal WWTPs in Austria (data without outliers)

From the analysis above it can be said that the variation in energy consumption depends mainly on the type of sludge stabilisation, which obviously depends on the size of a treatment plant.

Figure 6 illustrates the energy consumption related to the main and support processes. The figure shows that process 2 (mechanical-biological wastewater treatment) is by far the most relevant process not just with regard to water pollution control, but also with regard to energy consumption. All other main processes (process 1, 3 and 4) are from lower importance regarding energy consumption. The specific energy consumption for sludge thickening and stabilisation contributes with just 8 respectively 12% to the total energy consumption, because energy consumption for aerobic sludge stabilisation is allocated to process 2. The support processes (obligatory and optional processes) can be neglected with regard to energy consumption.

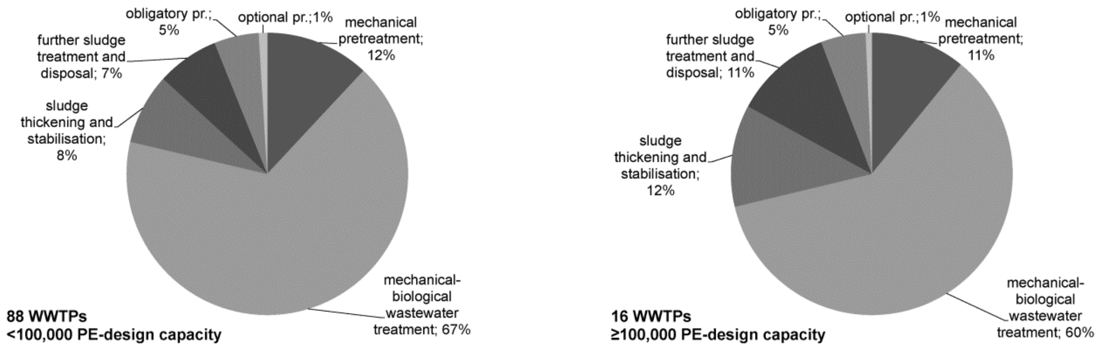
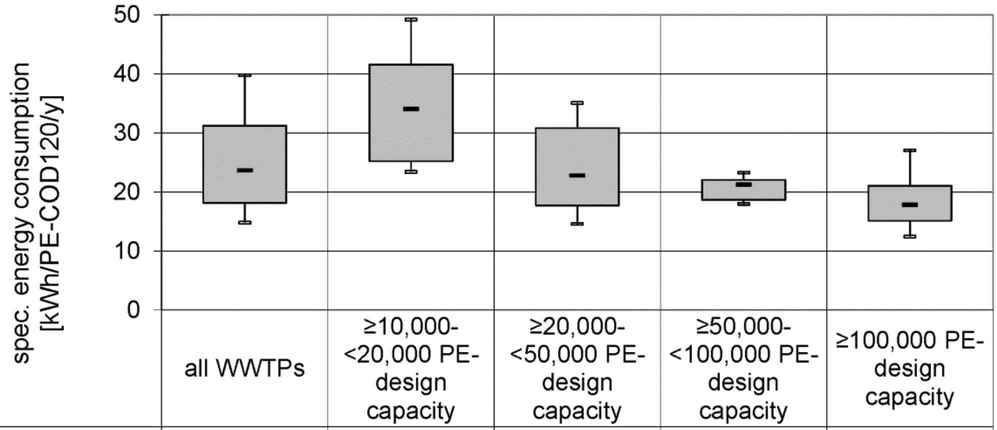


Figure 6: Distribution of processes of total energy consumption of small and large municipal WWTPs in Austria (data without outliers)

Due to the importance regarding energy consumption of process 2, a more detailed analysis was carried out. Figure 7 shows the specific energy consumption of process 2. The WWTPs are classified into different size groups. The figure shows the size-dependency of the process.



	all WWTPs	≥10,000-<20,000 PE-design capacity	≥20,000-<50,000 PE-design capacity	≥50,000-<100,000 PE-design capacity	≥100,000 PE-design capacity
number	102	24	55	7	16
75th percentile	31.3	41.6	30.8	22.1	21.0
90th percentile	39.8	49.2	35.1	23.3	27.1
10th percentile	14.8	23.4	14.6	18.0	12.4
median	23.7	34.0	22.8	21.2	17.8
25th percentile	18.2	25.2	17.7	18.7	15.1

Figure 7: Specific energy consumption of process 2 of municipal WWTPs in Austria (data without outliers)

Energy efficiency:

Energy-efficiency of WWTPs is from increasing interest, not only due to economic but also due to environmental aspects. Hence, the optimisation of energy consumption and generation on WWTPs is an important topic. Examples for energy self-sufficient WWTPs in

Austria are described in Nowak *et al.* (2011). The examination of the benchmarking data pool shows that 3 of the investigated large and 4 of the small WWTPs operate energy self-sufficient on a yearly basis.

Conclusions:

Based on a dataset of 104 WWTPs, this work analyses operating costs and energy consumption of municipal WWTPs in Austria. From the presented results, the following main conclusions can be drawn:

- Personnel costs are the most important cost element, distributing with more than 30% to the total operating costs.
- Energy costs distribute with only 17 respectively 11% to the total operating costs. However, with regard to environment protection, the reduction of energy consumption at WWTPs is crucial among the increase of energy production. But, as stated in Svardal & Kroiss (2011), energy minimisation must never negatively affect treatment efficiency due to the importance of water quality conservation.
- Process 4 (further sludge treatment and disposal) shows the highest cost-relevance of all main processes, distributing with about 30% to the total operating costs.
- The investigated large WWTPs show a yearly specific energy consumption of about 30 kWh/PE-COD120. In comparison, the specific energy consumption of smaller WWTPs is about 10 kWh/PE-COD120/y higher.
- Process 2 (mechanical-biological wastewater treatment) is by far the most important process regarding energy consumption (67 respectively 60% of total energy consumption). For the identification of further optimisation potential splitting of the process (e.g. aeration, mixing,…) would be necessary. Confirming Foladori *et al.* (2015) who stress the importance to collect relevant data for process optimisation.
- Operating costs and energy consumption decrease with increasing plant size (economy of scale). As the difference in energy consumption is mainly caused by the type of sludge stabilisation, smaller WWTPs with aerobic sludge stabilisation have a much higher specific energy consumption than large WWTPs with mesophilic sludge digestion.
- WWTPs can be operated self-sufficient on a yearly basis. Prerequisites for this are a small specific energy consumption and a high specific energy production (including digestion of co-substrate).

As for international comparisons a non-monetary evaluation is necessary, the cost relevance of the above-mentioned processes and cost elements was analysed. Furthermore the relevance of the above mentioned processes regarding energy consumption was illustrated. These results may serve as a basis for international comparisons regarding energy consumption of municipal WWTPs of different size groups and hence may help to identify inefficiencies at WWTPs.

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